

GALACTIC NUCLEI ACTIVITY SUSTAINED BY GLOBULAR CLUSTER MASS ACCRETION

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ABSTRACT. The decay of globular clusters to the center of their mother galaxy corresponds to carrying a quantity of mass sufficient to sustain the gravitational activity of a small pre-existing nucleus and to accrete it in a significant way. This is due to both *dynamical friction* of field stars and *tidal disruption* by the compact nucleus. The results of the simplified model presented here show that the active galactic nuclei luminosity and lifetime depend on the characteristics of the globular cluster system and are quite insensitive to the nucleus’ initial mass.

1. Introduction

It is commonly accepted that the active galactic nuclei (AGN) emission is due to the extraction of energy from the gravitational potential in form of mass falling onto a super-compact object. Most of the theoretical study is devoted to the geometry of the problem and to physical details in the attempt to explain some spectral characteristics and peculiarities of particular objects, rather than to answer the fundamental question:

–what is the actual source of the accreting mass?

Here we try to give an answer to this question, carrying evidence that spherical mass accretion on a compact object in form of dynamically decayed globular clusters in a (triaxial) elliptical galaxy can be the source of the power released by AGNs with-

out invoking ad hoc assumptions (see also Capuzzo–Dolcetta, 1993; Capuzzo–Dolcetta, 1997).

2. Observed spatial distributions of globular clusters

It is ascertained that the radial distribution of globular clusters in their parent galaxy is less peaked than that of bulge stars. For instance, recent Hubble Space Telescope observations of 14 elliptical galaxies (Forbes et al. 1996) confirm the general trend of flattening of the cluster distribution within 2.5 Kpc from the centre. This difference may be due to different initial conditions or to the evolution of the cluster system distribution (the bulge does not evolve due to its very long two-body relaxation time). This latter hypothesis is clearly the most “economical” and it has been already positively checked by Capuzzo–Dolcetta (1993). Here we mainly point the attention to one of the consequences that the evolution of the globular cluster system (GCS) has in terms of mass carried to the galactic centre.

3. Evolution of the globular cluster system

While the details of the general physical model can be found in Pesce, Capuzzo–Dolcetta and Vietri 1992, Capuzzo–Dolcetta 1993 and Capuzzo–Dolcetta (1997), here we just recall that the GCS evolution in an elliptical galaxy is due to the actions of *dynamical friction* (*df*) by field stars and of the *tidal* (*tid*) interaction with a compact object in the centre of the galaxy.

Dynamical friction is the decelerating effect due to the fluctuating gravitational field of the about 10^{11} stars of the galaxy where the massive globular cluster is orbiting. It is well known (see, e.g., Chandrasekhar 1943) that the cumulative gravitational encounters

of the satellite with much lighter stars result in a loss of both energy and angular momentum of the massive satellite. Detailed numerical integrations of globular cluster orbits in a triaxial potential for a set of initial conditions (see Capuzzo–Dolcetta 1993) allowed us to describe accurately the effects of dynamical friction on the orbital evolution of a GCS composed by clusters of different masses. Moreover, the time rate of energy and angular momentum decay is proportional to the satellite mass.

The destruction of clusters due to strong tidal interaction with a massive nucleus is, conversely, more effective for looser (so, usually, lighter) clusters (see Ostriker, Binney and Saha 1988).

As a consequence, the dynamical friction decay and tidal destruction time scales (τ_{df} , τ_{tid}) depend differently on the individual cluster mass and mass density. Of course, they also depend on the initial cluster energy, as well as on galactic potential and velocity distribution together with the nucleus mass (M_n). There is a competition between the two processes: dynamical friction is effective until a nucleus is accreted in mass enough to destroy the incoming clusters. This is shown by the expression of the ratio of the two time scales ($\bar{\rho}_h$ is the cluster density averaged over its half-mass radius)

$$\frac{\tau_{tid}}{\tau_{df}} = f(E) \sqrt{\bar{\rho}_h} \frac{M}{M_n}, \quad (1)$$

where $\bar{\rho}_h$ is the cluster density averaged over its half-mass radius, M is the mass of the cluster, M_n is the nucleus mass and $f(E)$ is a known function of the cluster orbital energy.

The possibility of a self-regulated nucleus formation in a galaxy is, so, quite natural. Of course several questions have to be answered:

- (i) when are τ_{tid} and τ_{df} sufficiently short to be relevant in the life of a galaxy?

(ii) is it possible to build up a compact nucleus in the galactic centre in the form of dynamically decayed globulars?

(iii) what fraction of the mass of frictionally decayed and tidally destroyed clusters is swallowed in the compact nucleus?

(iv) can a quasar-like emission be explained by such kind of spherical accretion?

A definite quantitative answer to question (ii) will require an accurate modelization. Such a modelization is in preparation, and it will consist of N-body simulations of the evolution of a set of globular clusters with different initial mass and internal mass spectrum along their orbits in a galactic triaxial field in presence of a central compact nucleus (Capuzzo-Dolcetta and Miocchi 1997). This will allow to see under which conditions a globular cluster can release stars to be swallowed by the nucleus, so to feed its activity. The questions (i), (iii) (as well as (iv)) have been answered in Pesce et al. (1992), Capuzzo-Dolcetta (1993), Capuzzo-Dolcetta (1997), and will not be discussed here.

In what follows we limit ourselves to give support to a positive answer to question (iv).

4. The model

A black hole of given mass m_{bh} which stays at the galactic centre is able to swallow the surrounding stars entering a destruction radius $r_d = \max(r_S, r_t)$ where r_S is the Schwarzschild's radius and r_t the tidal-breakup radius, defined as

$$r_t = \left(\frac{m_{bh}}{\langle M_* \rangle} \right)^{\frac{1}{3}} < R_* >,$$

with $\langle M_* \rangle$ and $\langle R_* \rangle$ mass and radius of the typical star. The resulting rate of

(spherical) mass accretion is \dot{m}_{bh} , which yields a gravitational luminosity

$$L_n = \dot{m}_{bh}\phi$$

where ϕ is the gravitational potential near r_d . The mass accretion rate and the corresponding luminosity crucially depend on the star density (ρ_*) and velocity dispersion ($\langle v_*^2 \rangle^{1/2}$) around the black hole through

$$\dot{m}_* = -\sigma_* \rho_* \langle v_*^2 \rangle^{1/2} \quad (2)$$

$$\sigma_* = \pi r_d^2 \left(1 + \frac{\frac{Gm_{bh}}{r_d}}{\frac{1}{2} \langle v_*^2 \rangle} \right) \quad (3)$$

$$\dot{m}_{bh} = -\dot{m}_* \quad (4)$$

$$L_n = \eta \dot{m}_{bh} c^2 \quad (5)$$

where \dot{m}_* is the rate of stellar mass swallowed in the black hole and η is an efficiency factor, of the order of 10%. Of course higher ρ_* corresponds to higher \dot{m}_* , while a high stellar velocity dispersion $\langle v_*^2 \rangle^{1/2}$ favours nucleus accretion increasing the capture time rate but, at the same time, decreases the swallowing cross section (3).

Capuzzo–Dolcetta (1997) showed that the nucleus accretion rate can easily increase up to few $M_\odot yr^{-1}$ due to stars of frictionally decayed globular clusters and to tidally disrupted clusters. This accretion rate is exactly of the order of that needed to sustain a typical quasar activity (note that the high velocity bulge stars cannot provide for more than $10^{-7} - 10^{-6} M_\odot yr^{-1}$).

5. Results

Here we report of some results of a model where the GCS is composed by clusters all of the same mass and having an initial density distribution and velocity dispersion equal to those of bulge stars' in a typical triaxial galaxy.

Figure 1 a) shows the time evolution of the nucleus luminosity for different choices of the initial black hole mass m_{bh0} ($10, 10^2, 10^3, 10^6 M_\odot$). It is remarkable how, independently of m_{bh0} , the highest luminosity reached, L_{max} , is similar (L_{max} varies for a factor of 10 when m_{bh0} ranges between 10 to $10^6 M_\odot$). The nucleus luminosity has a short super-Eddington burst, a factor 10^3 brighter than the luminosity when a relatively slow dimming phase starts (the noise in the figure is real, due to the graininess of the problem amplified by the non-linear coupling of source and sink term in the dynamical equations). Of course L_{max} is attained later for smaller values of m_{bh0} , for it requires longer to accrete enough mass onto the nucleus. In all the cases the nucleus starts brightening at about 1 Gyr. At that age enough massive globulars have frictionally decayed to the centre and released stars to the black hole. A flatter slope of $L_n(t)$ follows (at least for $m_{bh0} \geq 10^2 M_\odot$), due to that the less massive incoming clusters feed less the nucleus. The nucleus continues increasing its mass and becomes, rather quickly, an efficient tidal destroyer of clusters capable (in some cases) to keep within its potential well a large fraction of the dispersed cluster' stars, which are eventually swallowed. Figure 1 b) shows that the central black hole mass stabilizes around a value ($\approx 5 \times 10^8 M_\odot$ in this model) which is about the same irrespectively of its initial value.

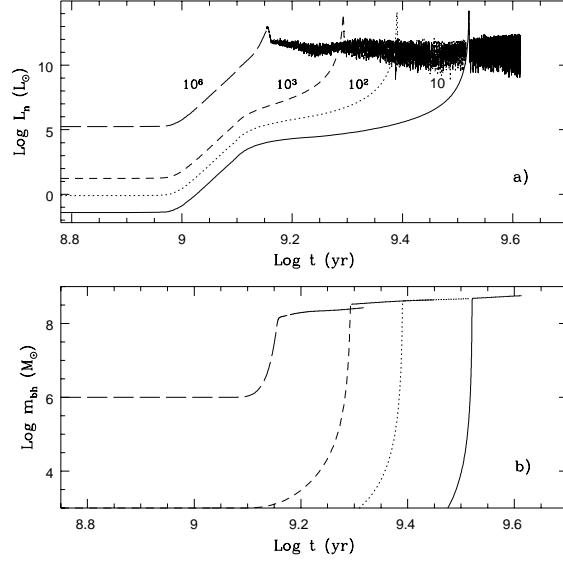


Fig. 1.

panel a): time evolution of the nucleus luminosity, for various initial nucleus masses (as labeled in M_\odot) ; panel b): time evolution of the nucleus mass, for the same initial values as in panel a).

6. Conclusions

A possible mechanism to accrete a compact nucleus in the centre of a triaxial galaxy is the swallowing of surrounding stars, which belong either to dynamically decayed clusters either to tidally destroyed ones. Quantitatively speaking, the relevance of such phenomenon depends on the orbital structure of the GCS and on its mass and internal density spectrum: a low-velocity dispersion system composed by massive, dilute clusters is the most affected by both dynamical friction and tidal erosion. In the model here presented, and deeply discussed in Capuzzo–Dolcetta (1997), the peak of the rate of mass accretion and the final value of the nucleus mass are remarkably independent (for

a fixed typical globular cluster mass) of the initial black hole mass. What can vary is the age of occurrence of the resulting luminosity peak ($10^{13} \div 10^{14} L_{\odot}$) and of the flattening of the mass growth curve. Infact, we found that the black hole mass grows rapidly until it reaches a value of few $10^8 M_{\odot}$; after that the mass accretion is much slower.

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